Characterizing Exoplanet Atmospheres:
a new frontier

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Are we alone?

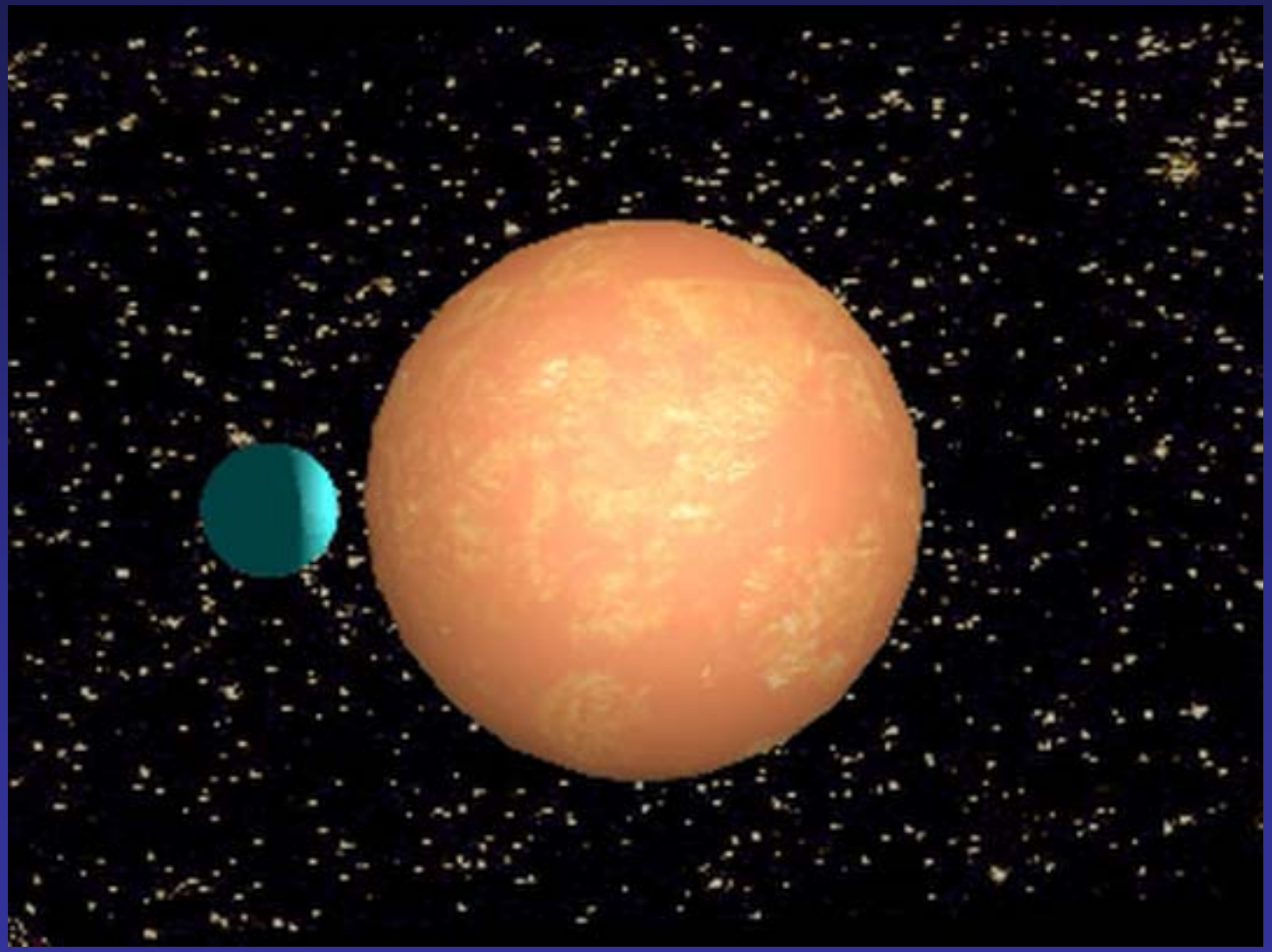
To answer the question: "Are we alone?"

- Are there planets around other stars? (exoplanets)
- Could they support life?
- What kind of atmosphere?
- Are organic molecules present?
- Are there "biomarkers"?

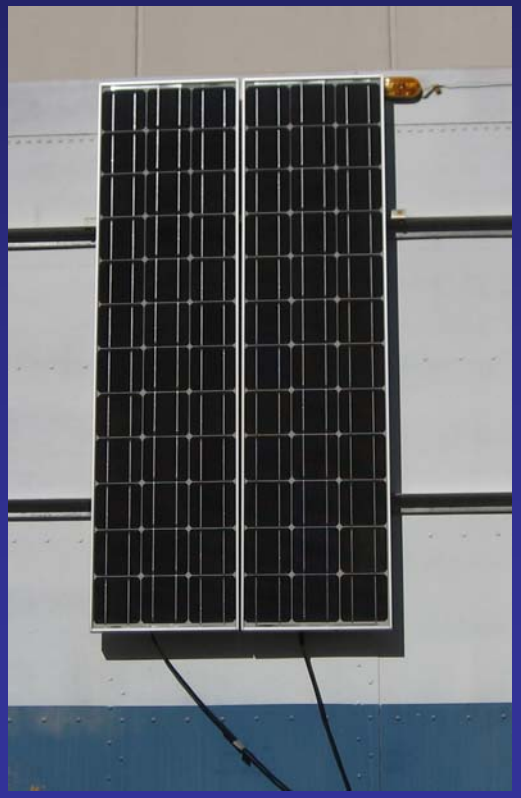
Primary tools:

- Planet detection
  - Doppler effect
  - Transit detection
- Atmospheric characterization
  - Photometry
  - Spectroscopy

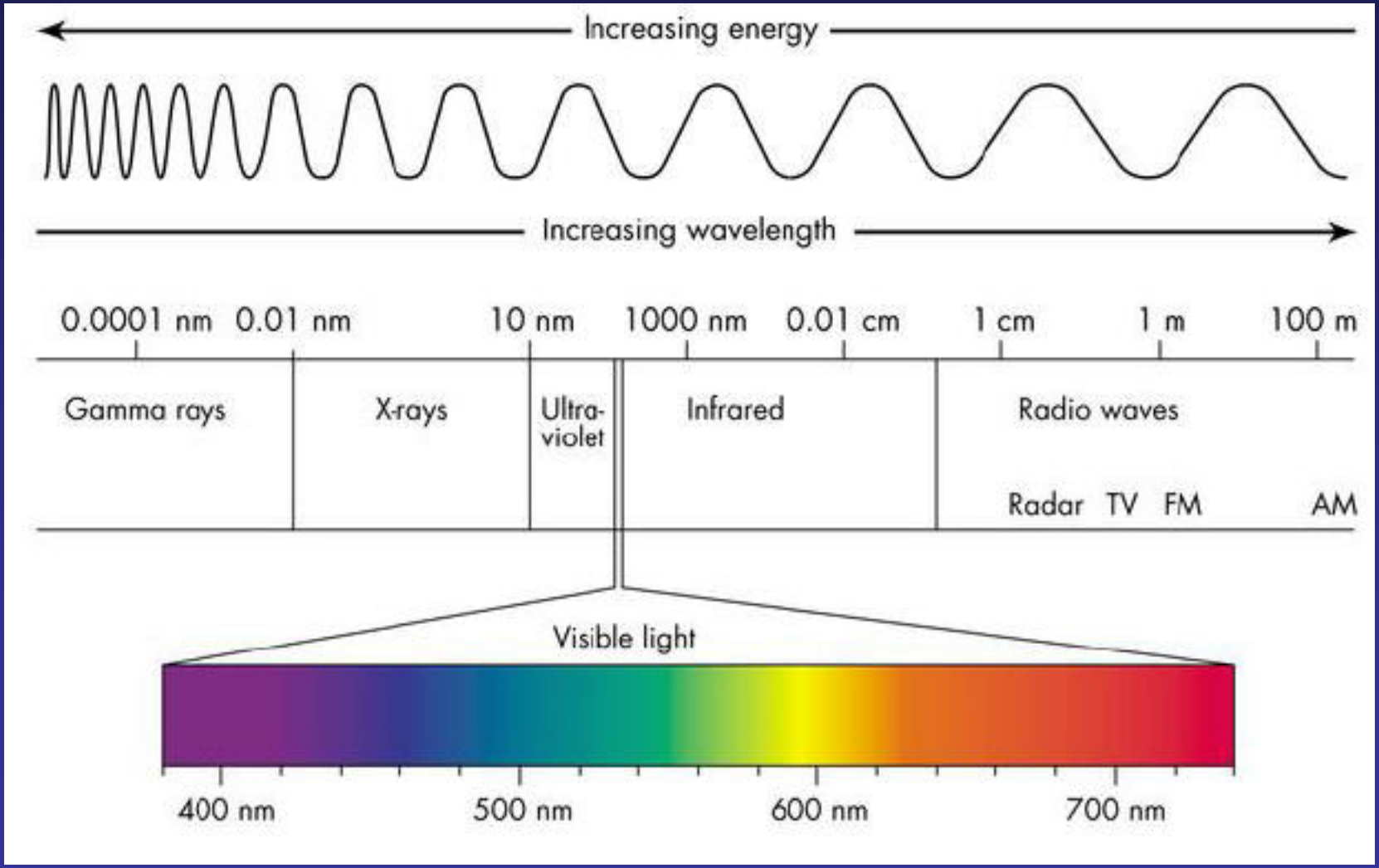
Transit detection:



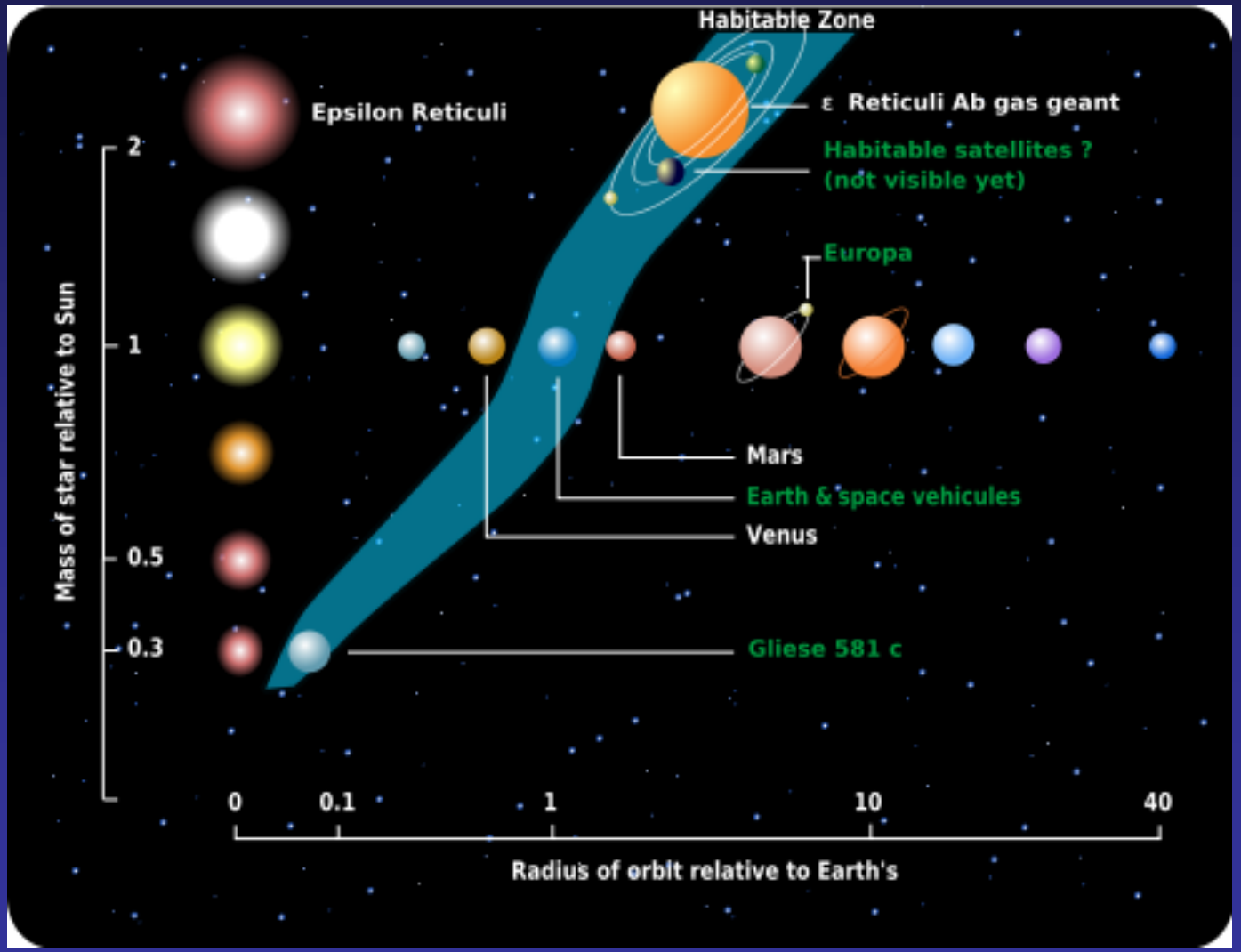
Photometry:



Spectroscopy:

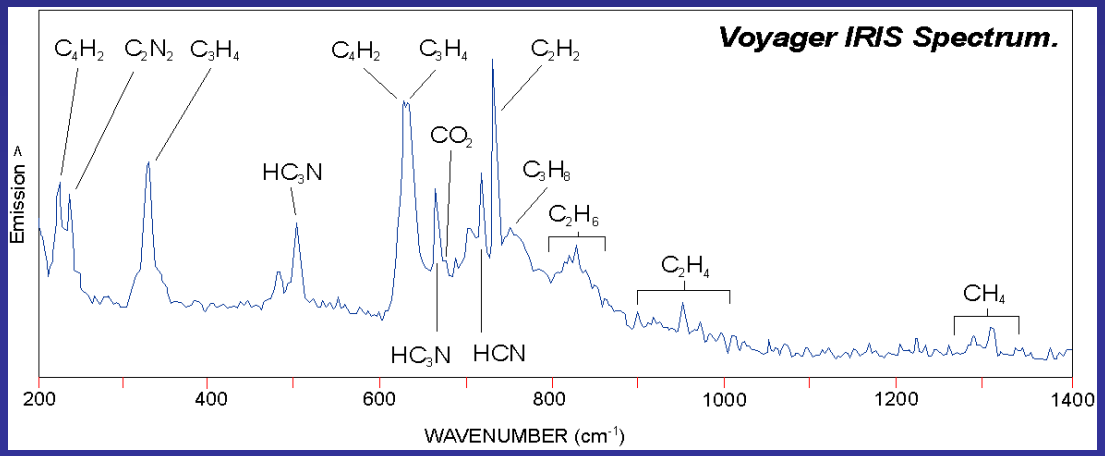


Habitable-zone planets



Characterizing Exoplanet Atmospheres

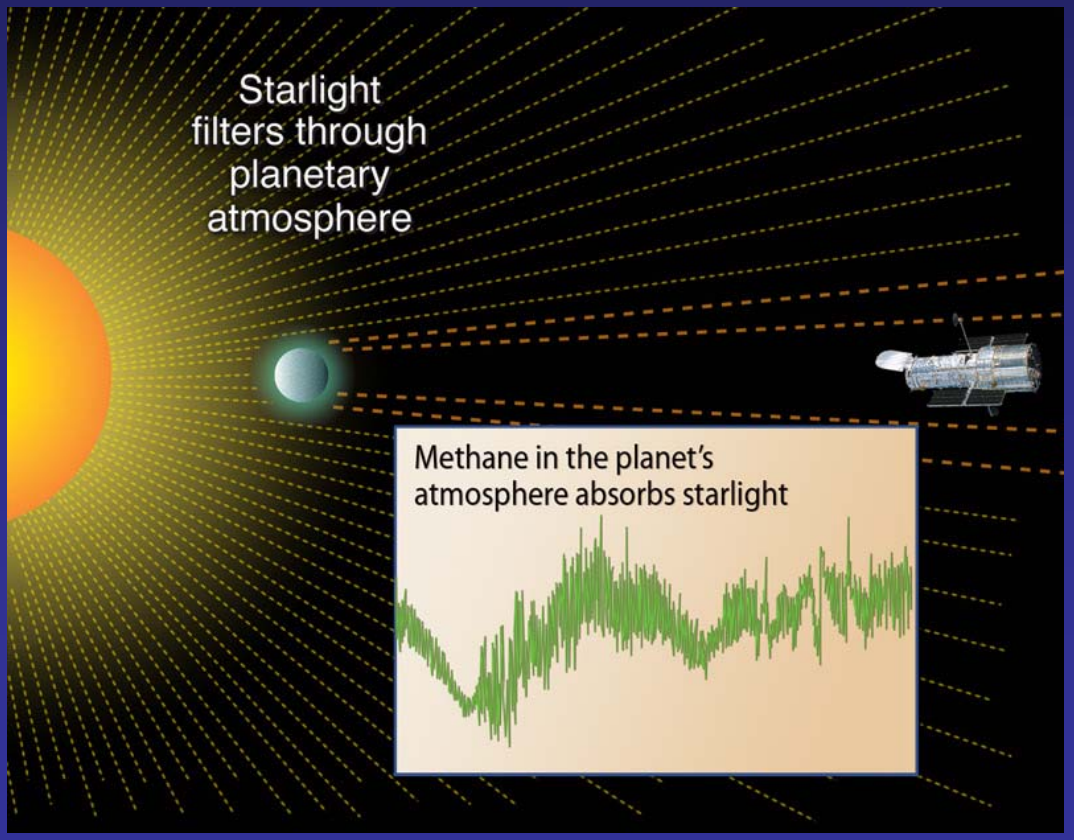
- Temperature & composition
- Vertical “structure”
- Heat transport & weather
- Molecules & chemistry
- Photometry & spectroscopy
- Visible light probes atomic species and haze
- Infrared light probes molecules



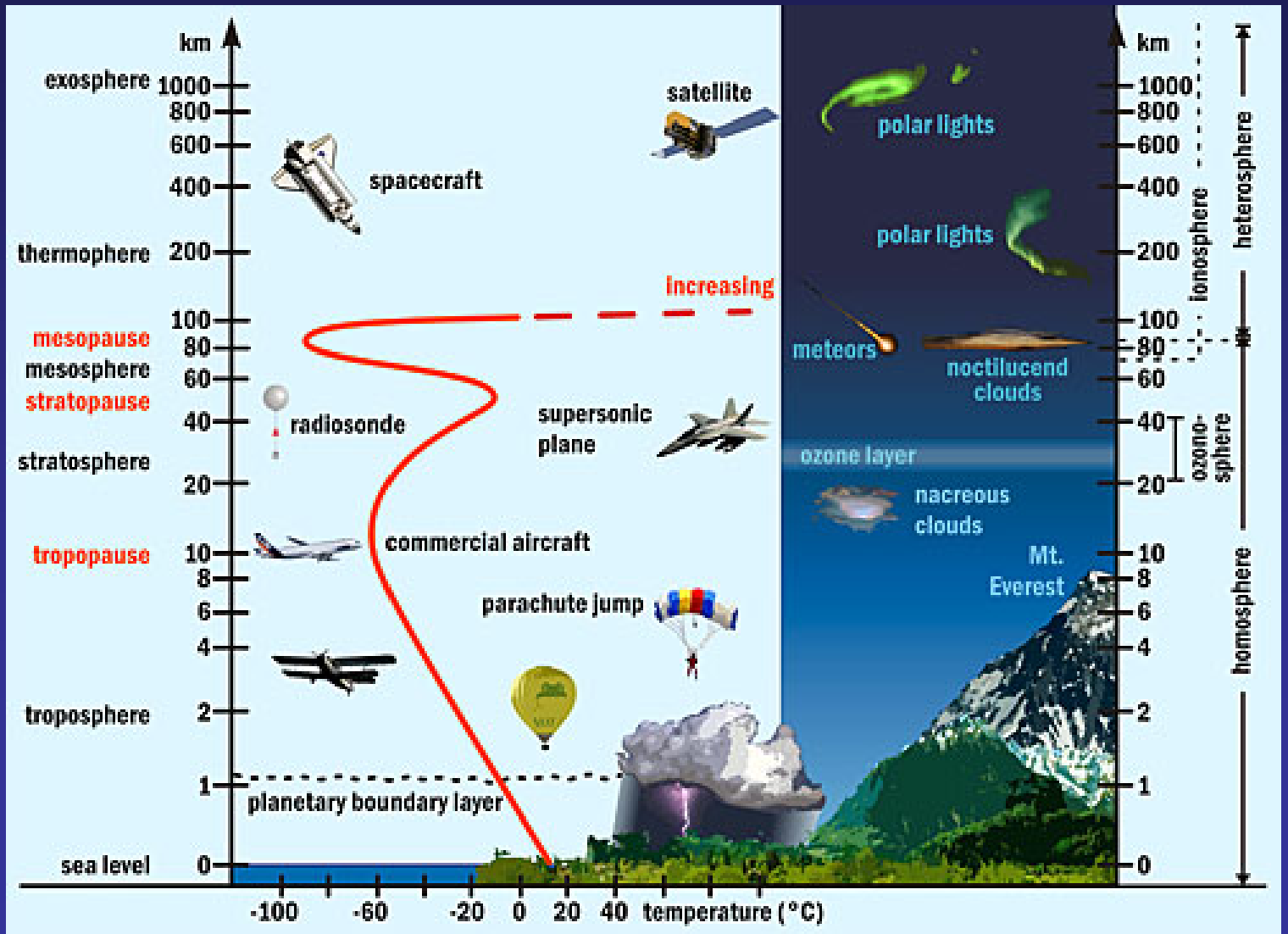
Why study molecules?

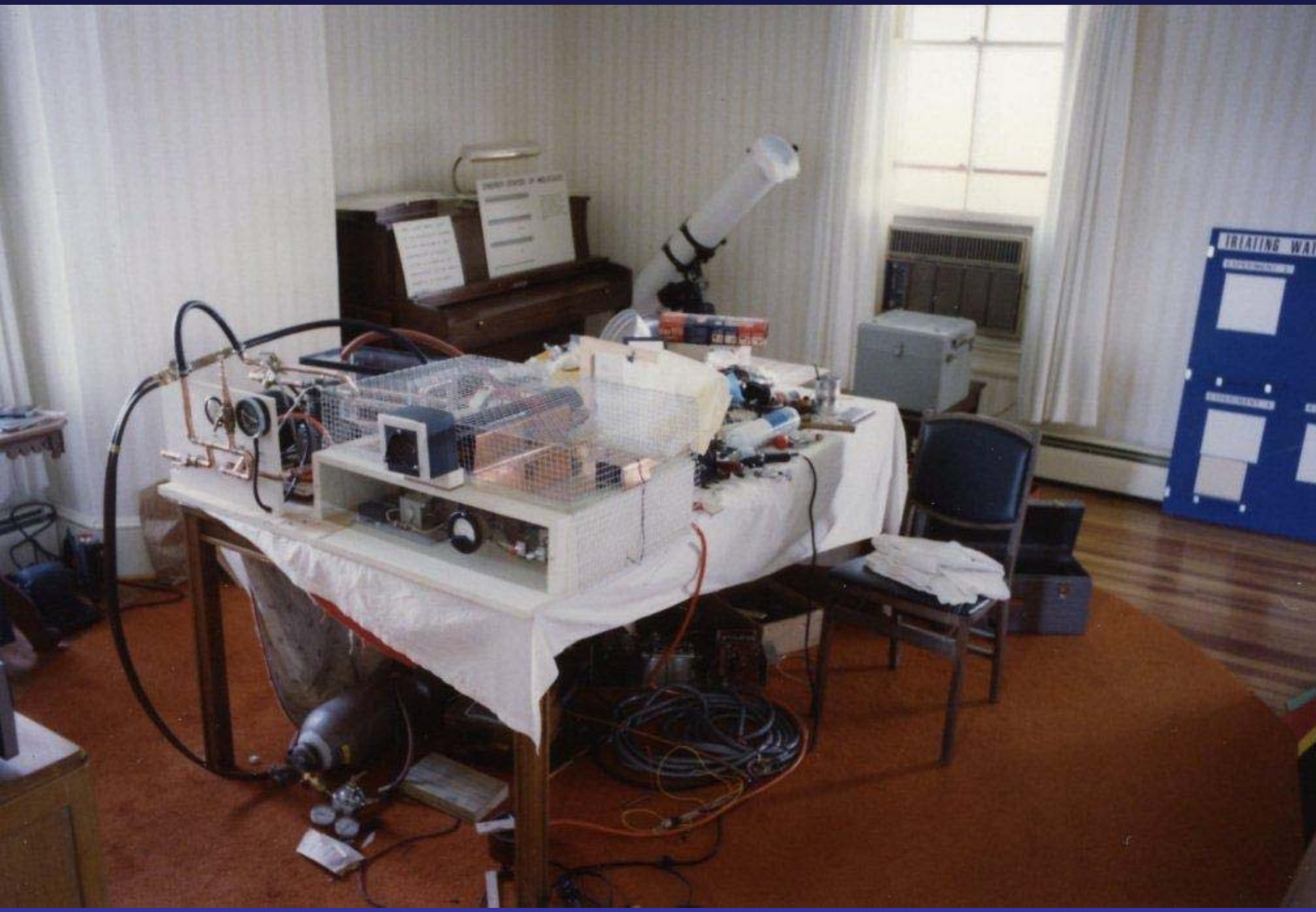
Molecules serve as probes of:

- *Conditions*
- *Composition*
- *Chemistry*
- *History*

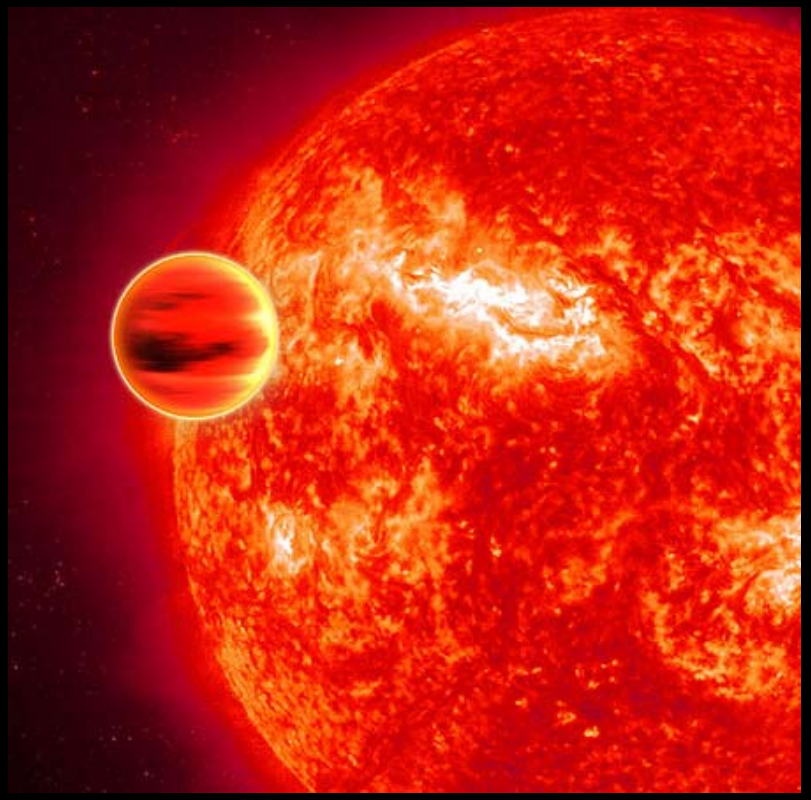


Context: Earth's Atmosphere




IRRIGATING WAT

Finding the exoplanets

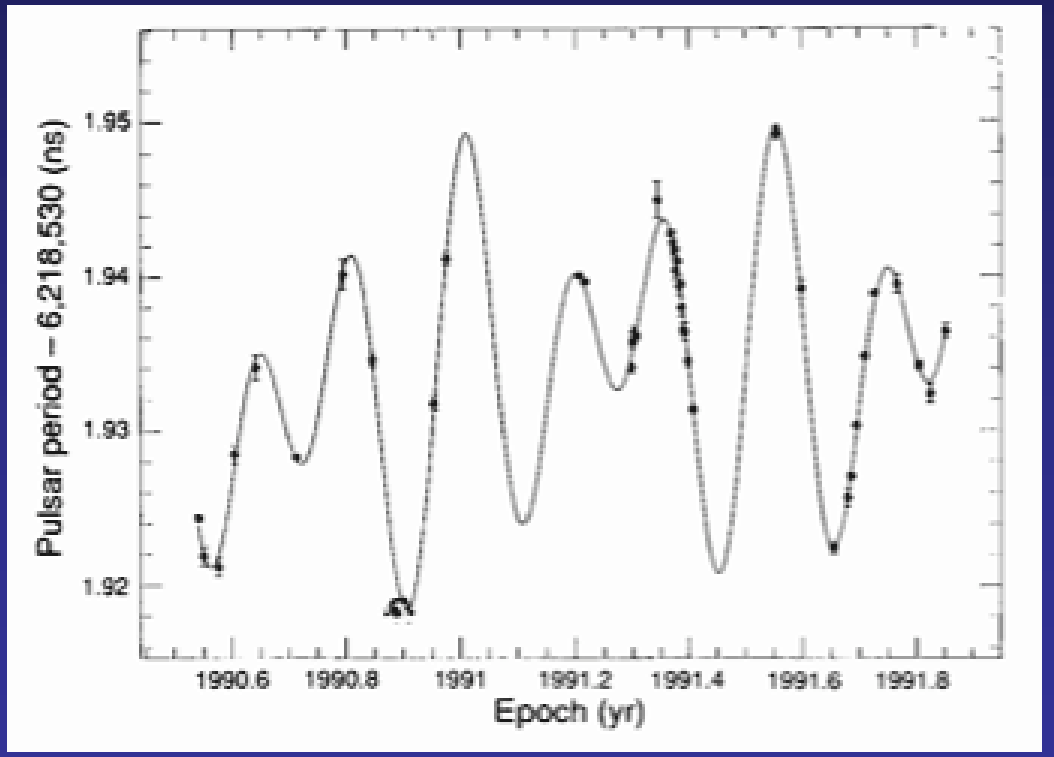


An exoplanet system

around a pulsar

Two planets
PSR1257+12
2.8 & 3.4 M_E
89.2 & 66.6 day orbits
Wolszczan & Frail 1992, Nature

courtesy of the NAIC - Arecibo Observatory, a facility of the NSF



51 Peg: a new era

a big surprise

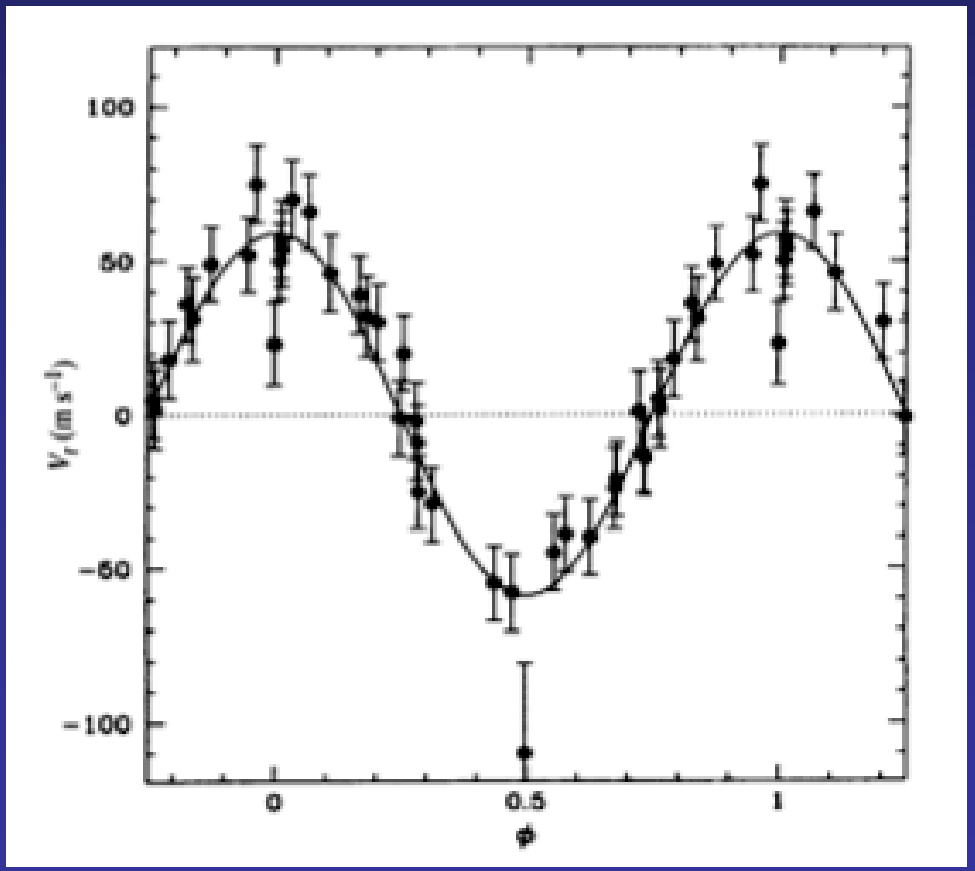
Single planet

Solar type host

1.2 M_J

4.2 day orbit

Mayor & Queloz 1995, Nature

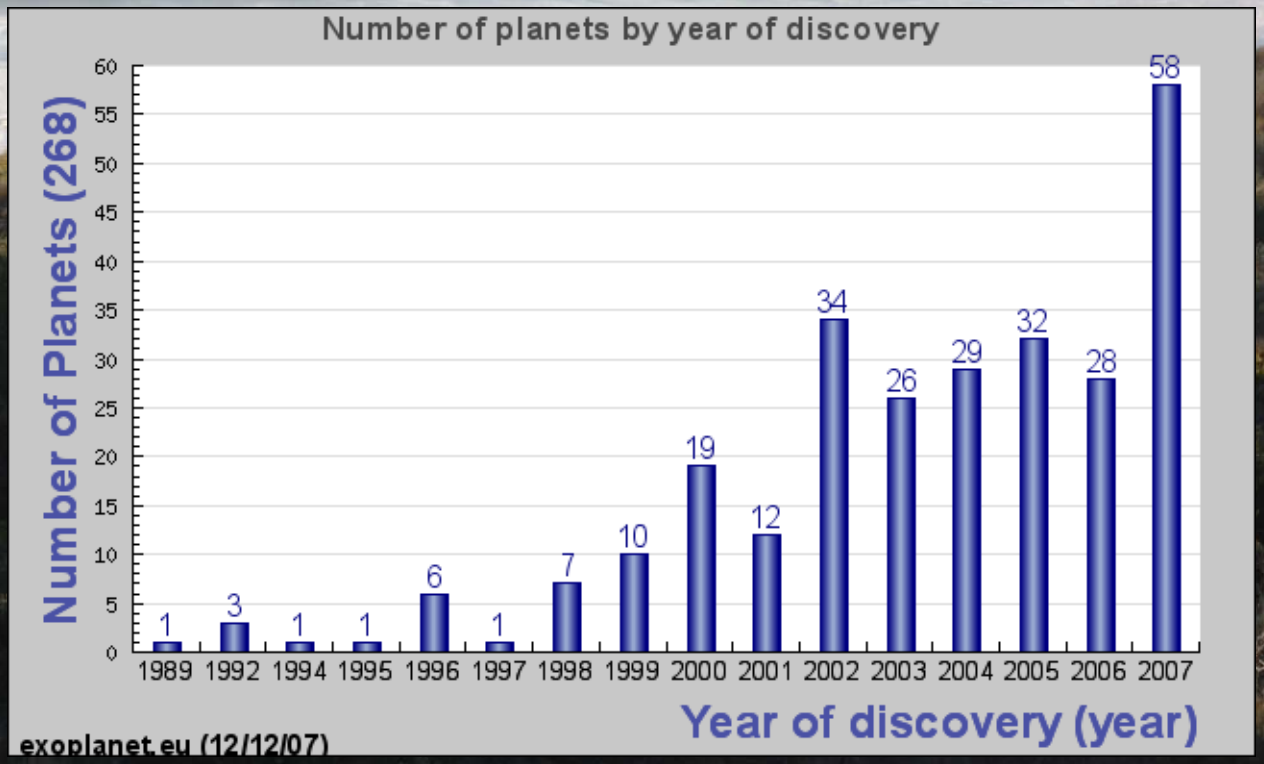


Popular Interest

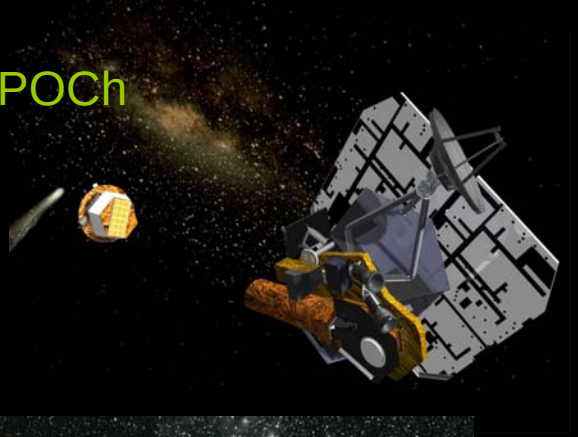
Exoplanet detections:

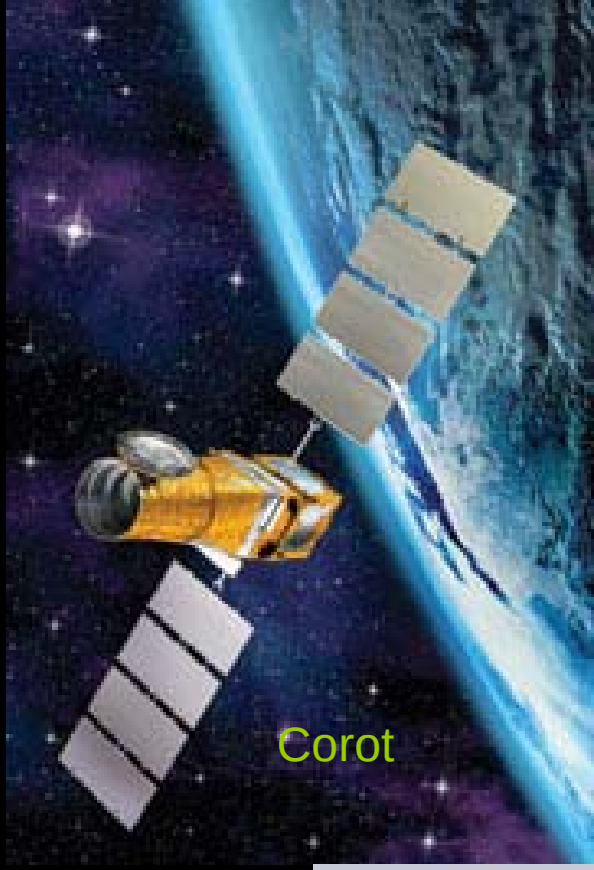
A rising tide

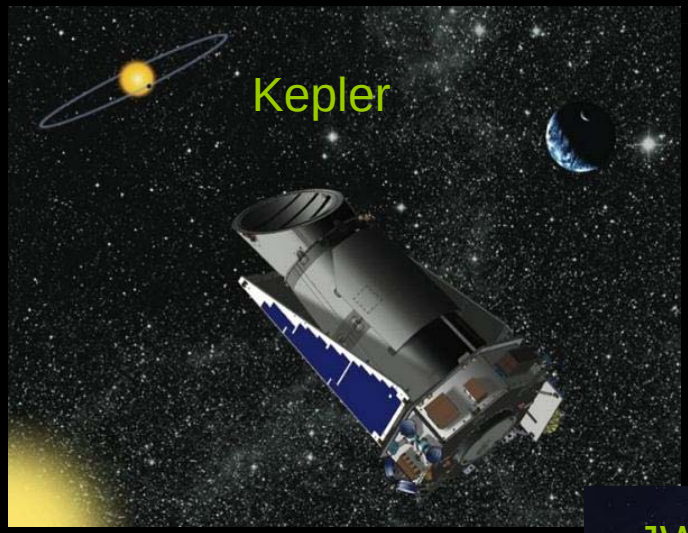
- 303 planets
- Doppler & transit measurements
- Multiplanet systems
- Habitable-zone planets
- 51 transiting planets

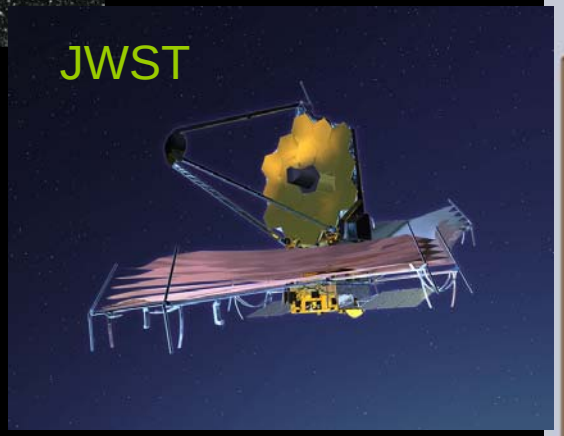


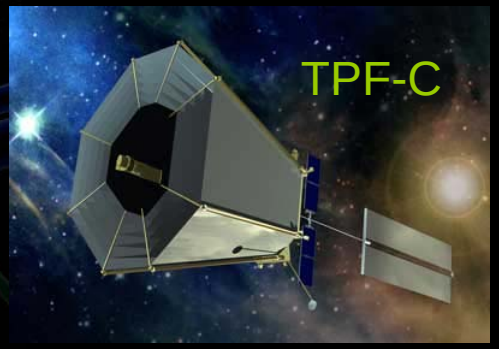
Missions



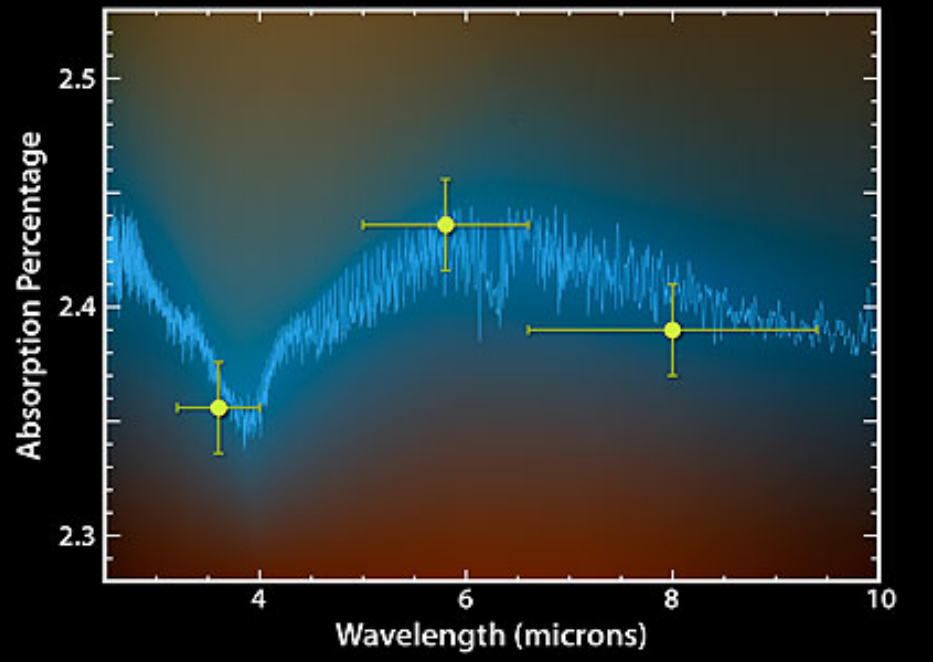








Characterizing atmospheres



Exoplanet science:

an exceptional period

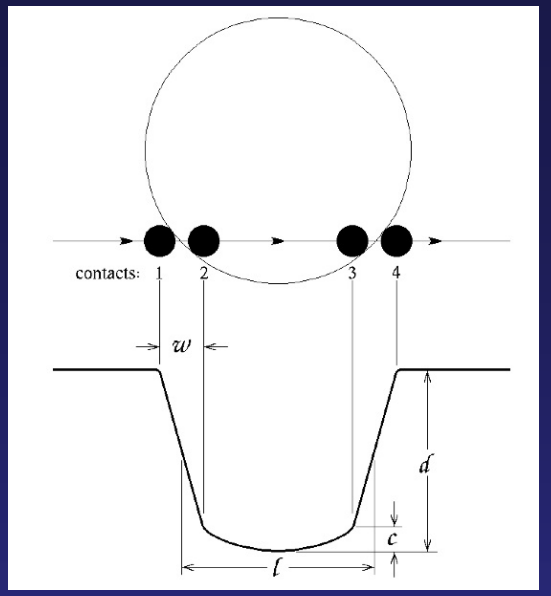
- Transition period
- “break through” or “transformational” science
- changing the way we think about exoplanets

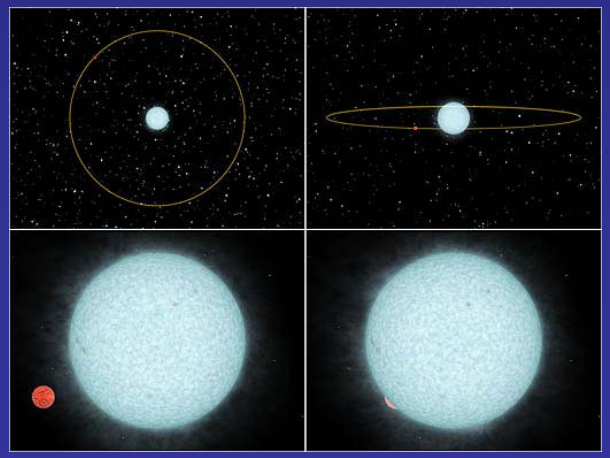
2005
Does it exist?
Temperature?
Is it a rock?

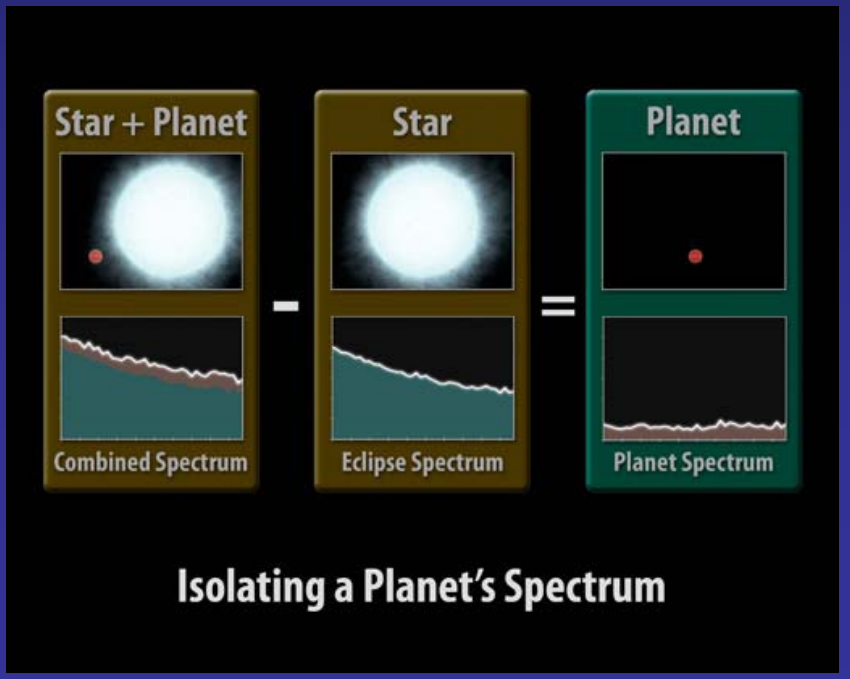
2008
Weather forecast
What causes smog
Prebiotic molecules

Transiting planets:
something special

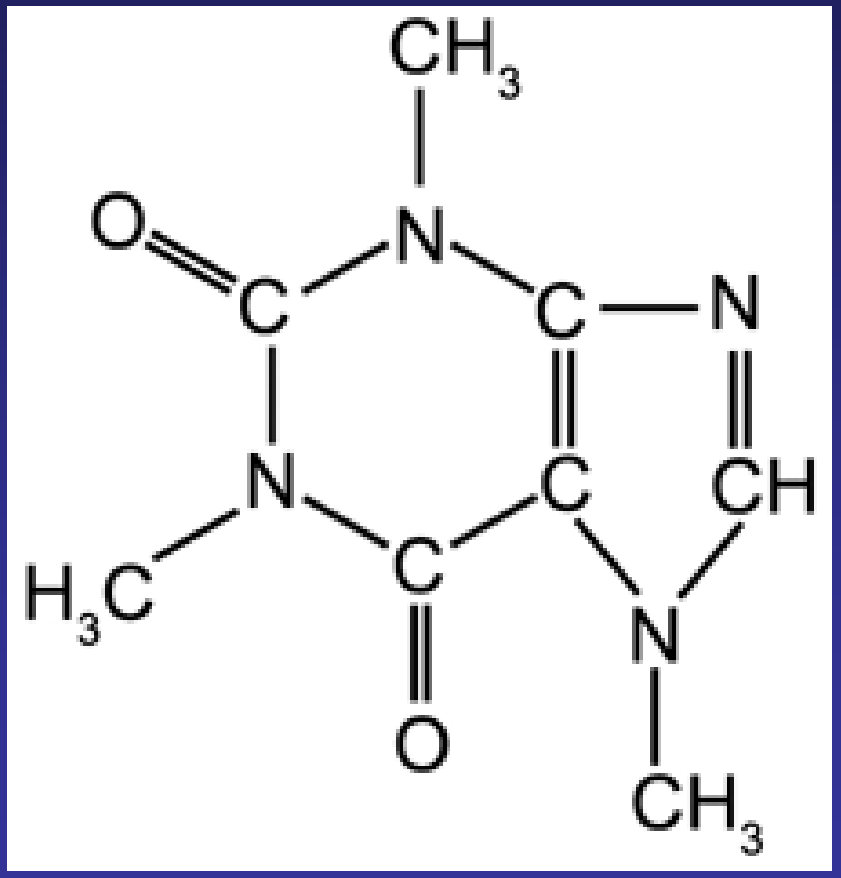
- Primary eclipse
  - Blocks starlight
  - Starlight filters through planet atmosphere
- Secondary eclipse
  - Light from planet blocked
- Both detected by measuring intensity as a function of time

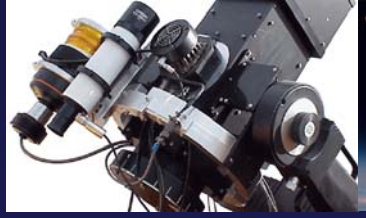






The molecule I hope to find in an exoplanet atmosphere…

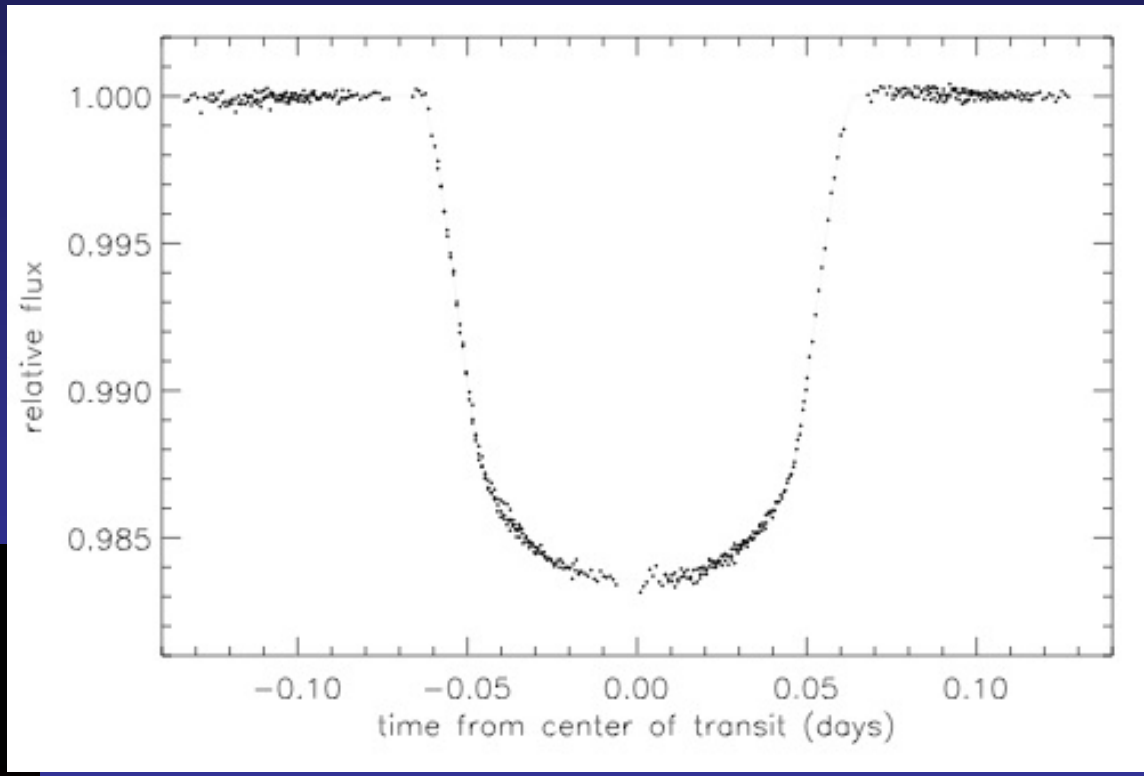


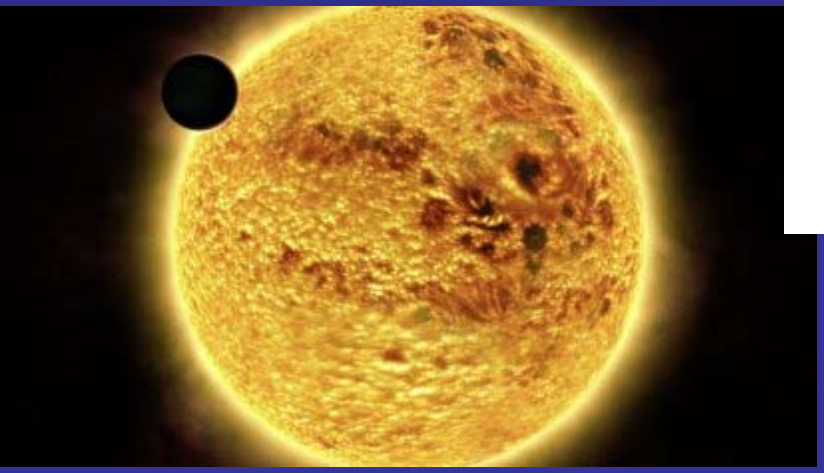


Density measured

2001: first transit detection

- Diameter & density
- Orbital parameters
- Unseen companions



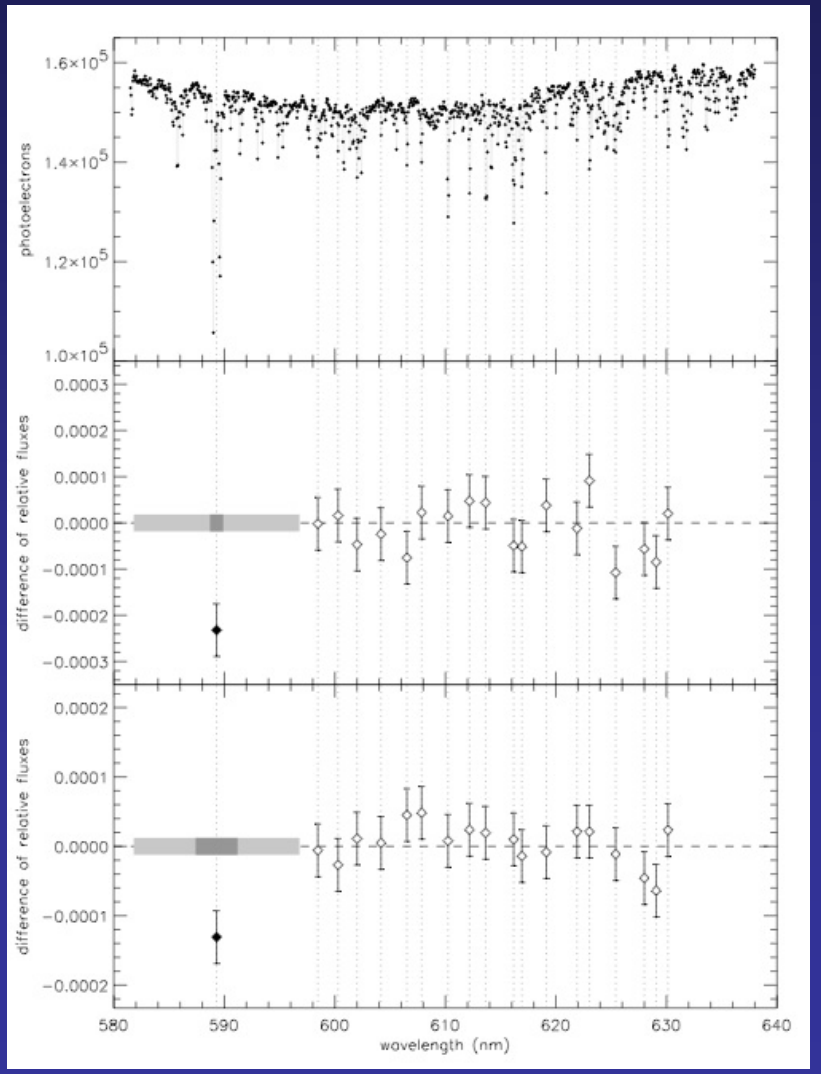


Brown & Charbonneau

An atmosphere detected

2002: first transmission spectrum

- Light filters through the “limb”
- Some atoms or molecules will absorb specific wavelengths - leaves a “fingerprint”
- Reveals atmospheric composition

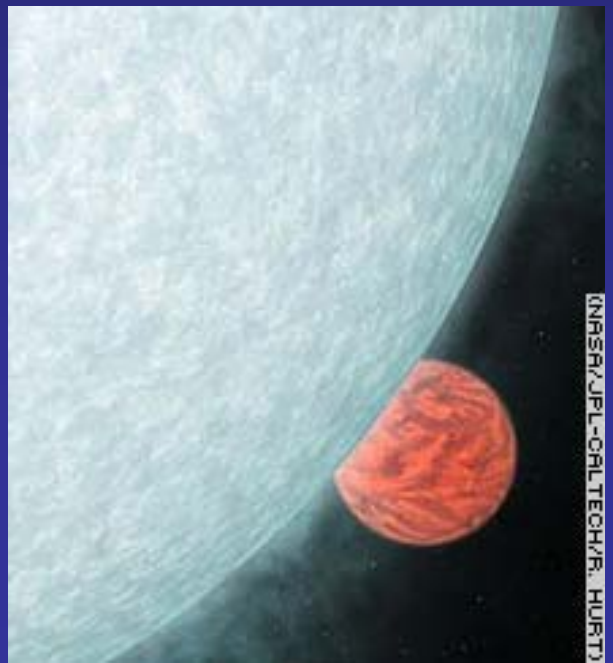


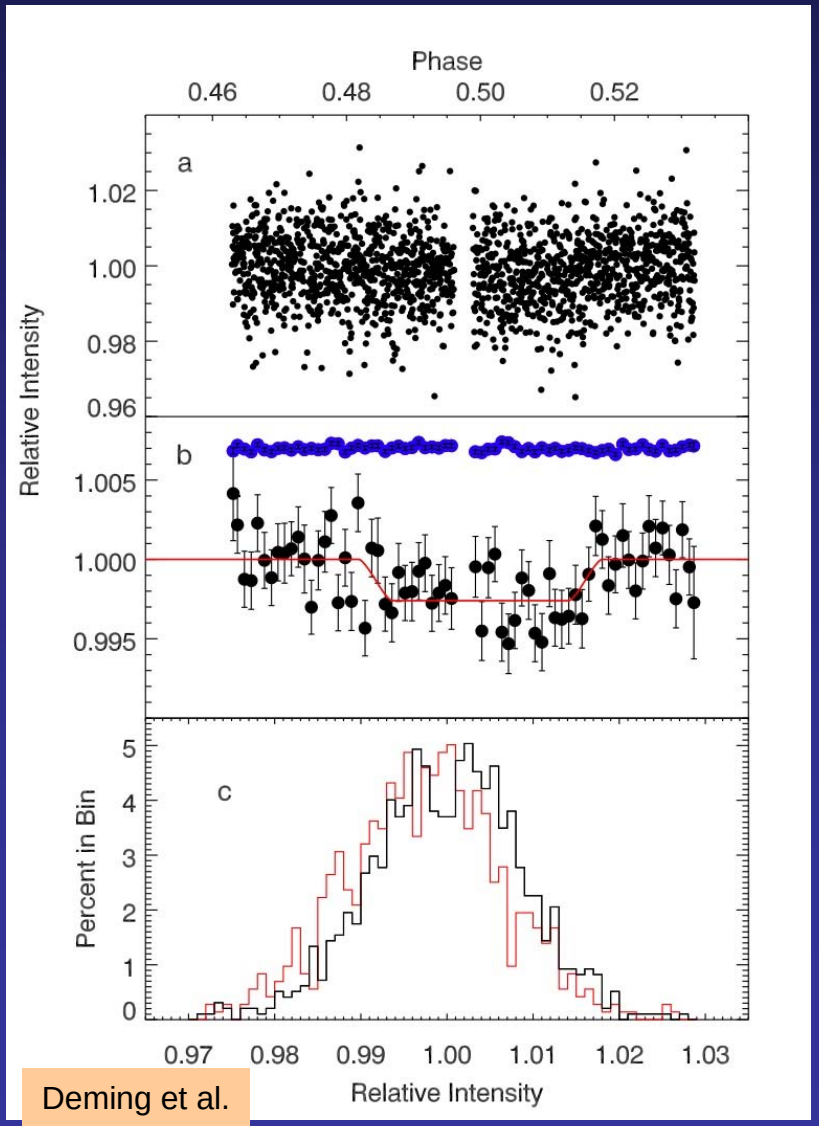
Charbonneau et al.

Temperature measured

2005: first emission detected

- Requires working in infrared
- Small signal = difficult!
- T = 1500 K



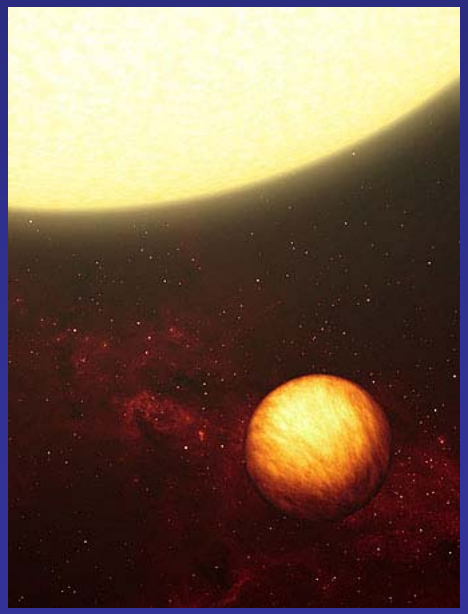


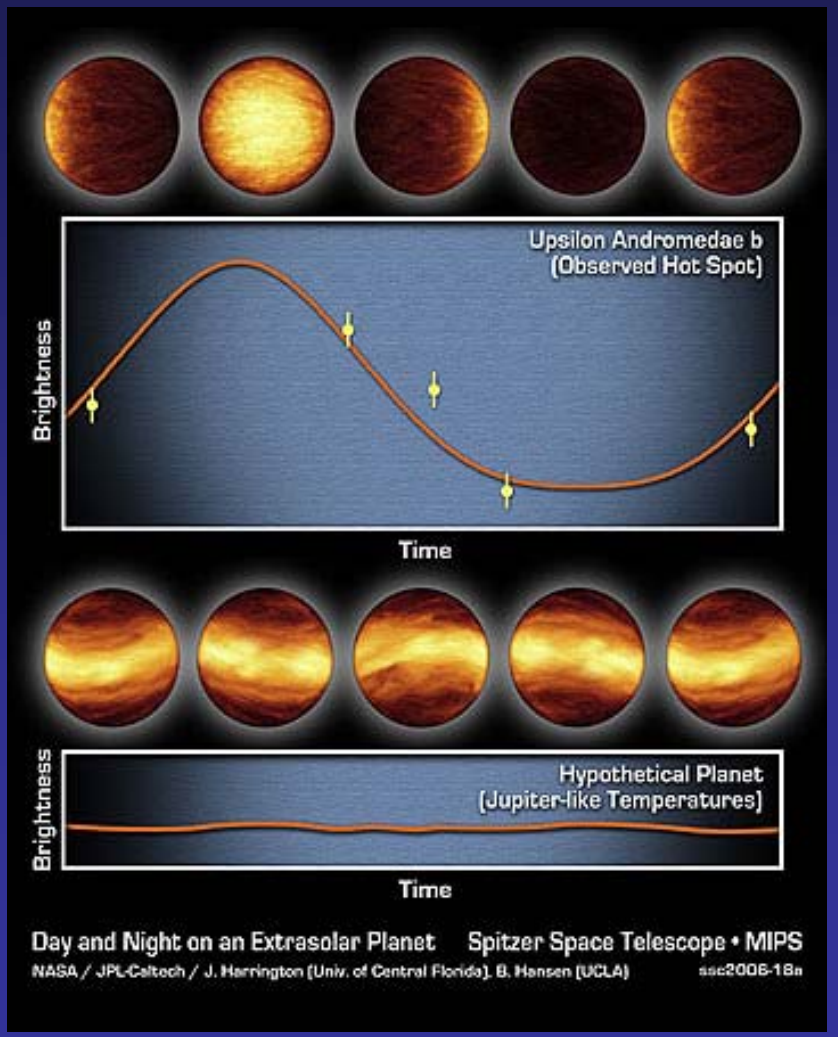
Deming et al.

Upsilon Andromeda

2006: non-transiting light curve

- Large day/night temperature difference
- A milestone



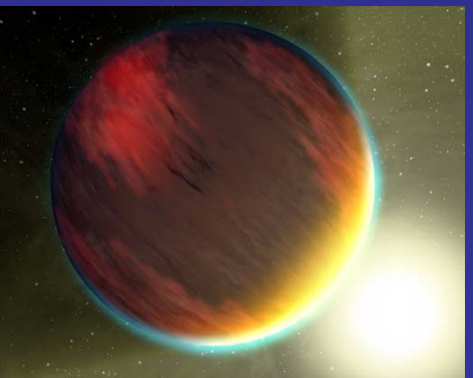


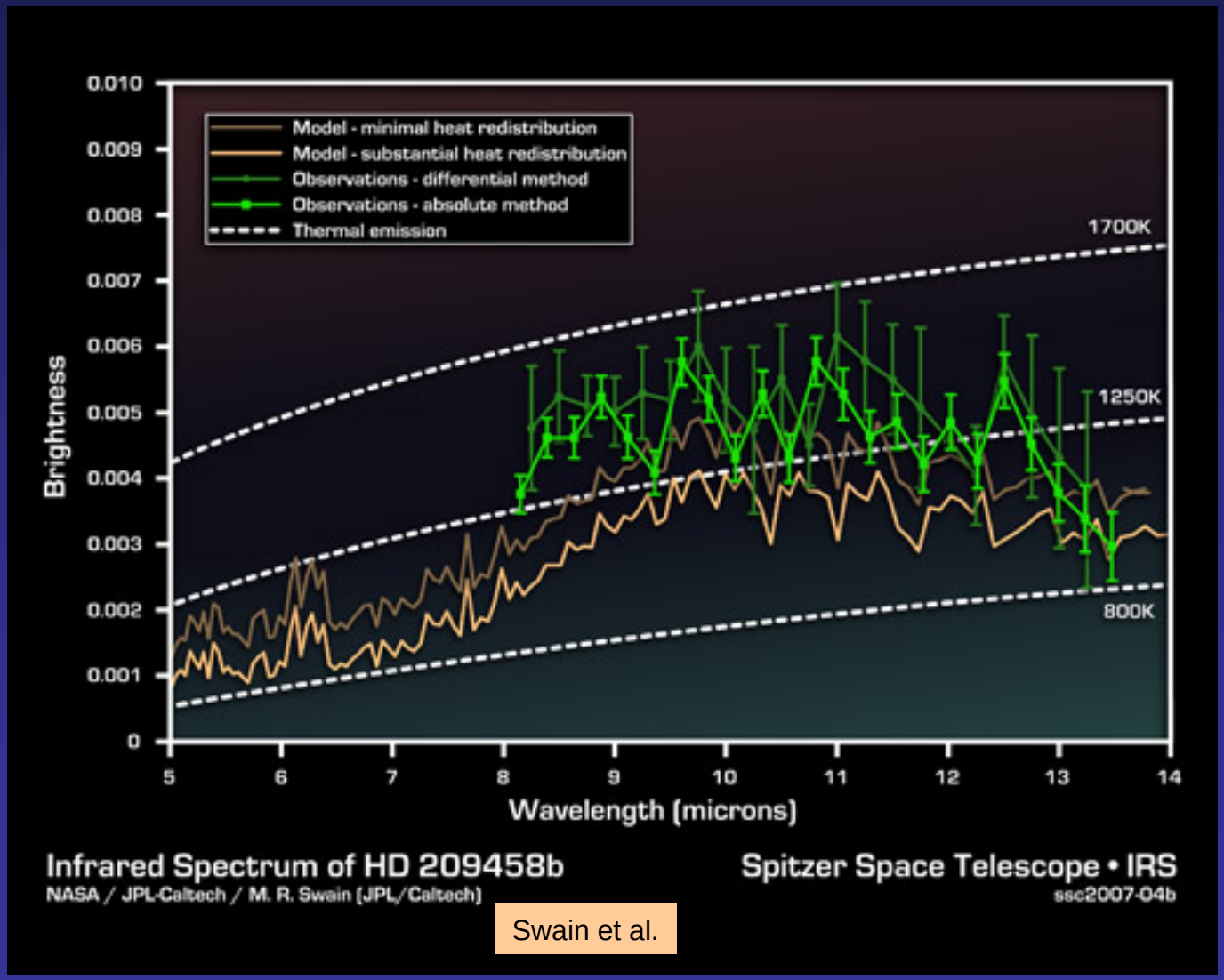
Harrington et al.

Emission spectrum 189 & 209

2007

Where is the water?
Not present?
Hidden by T profile?
Hidden by clouds?



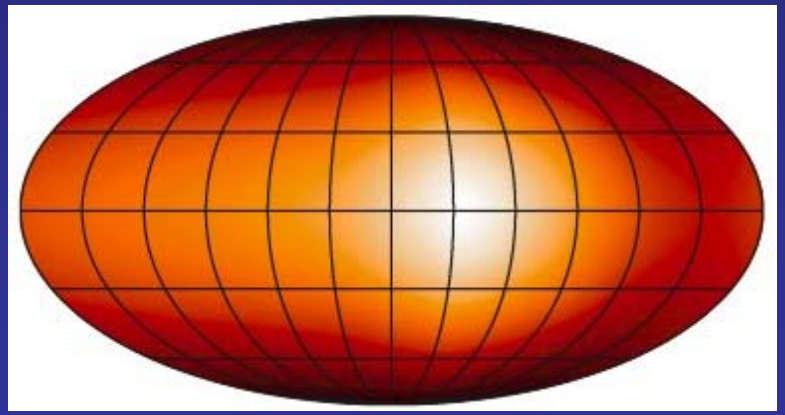


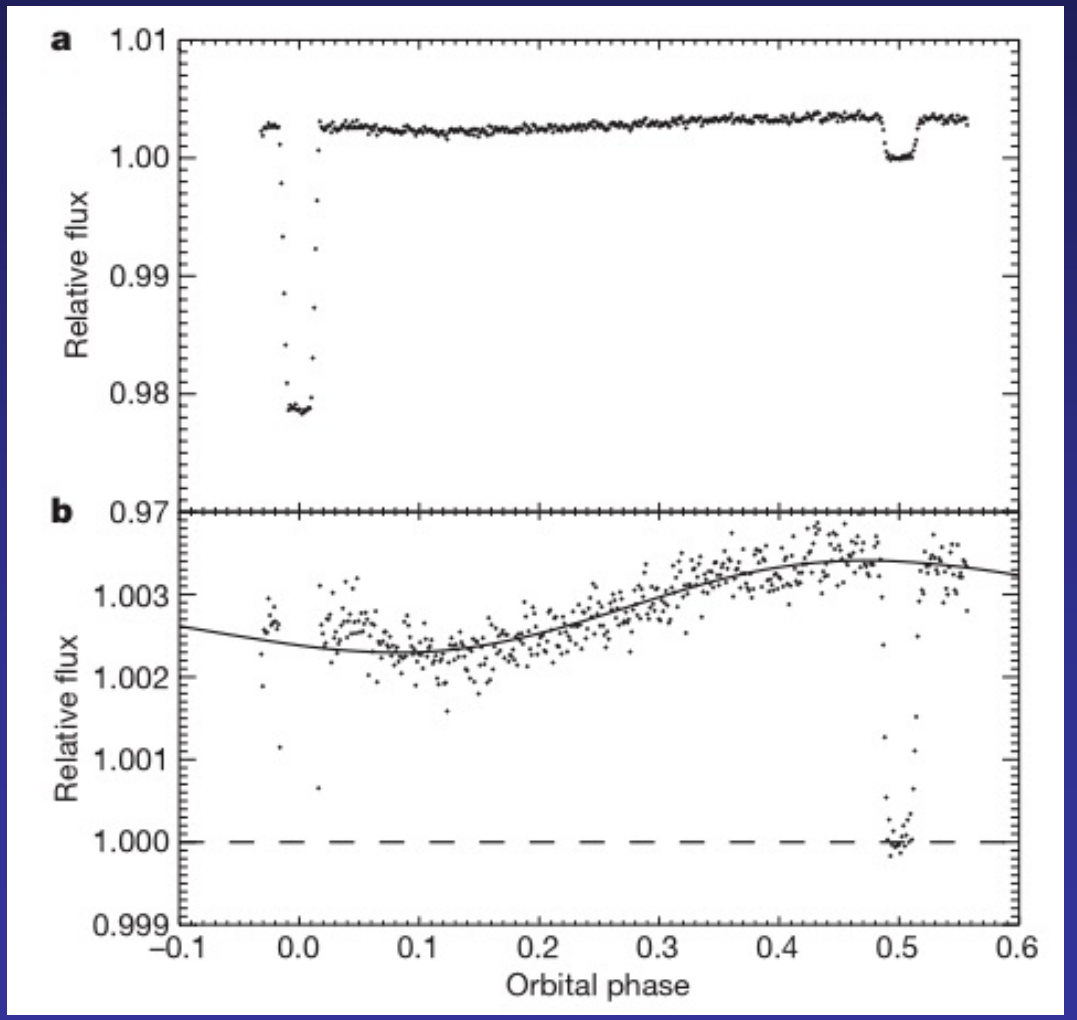
Swain et al.

Day and night detected on 189

2007:

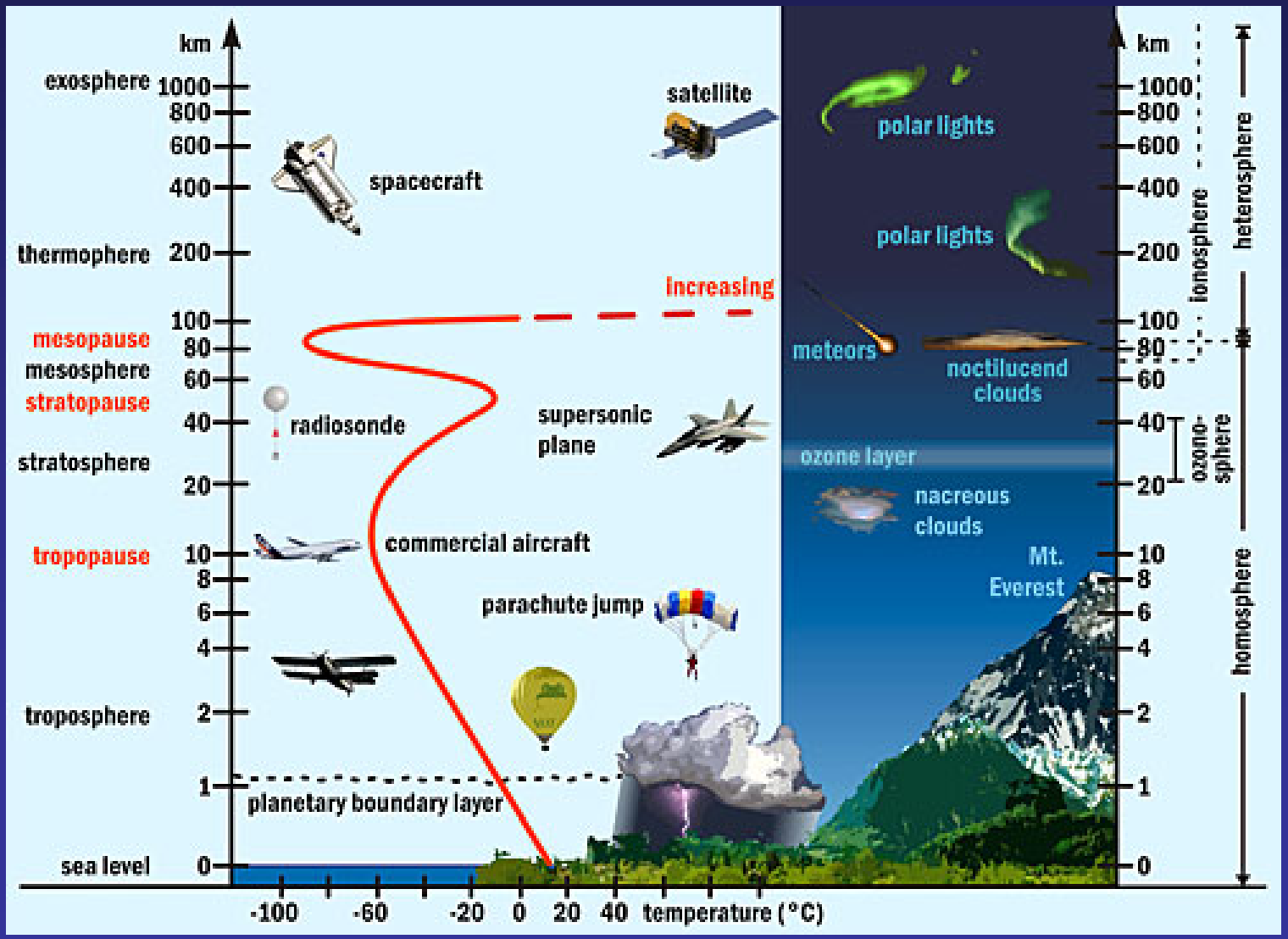
- Redistribution of heat
- Day and night temperatures





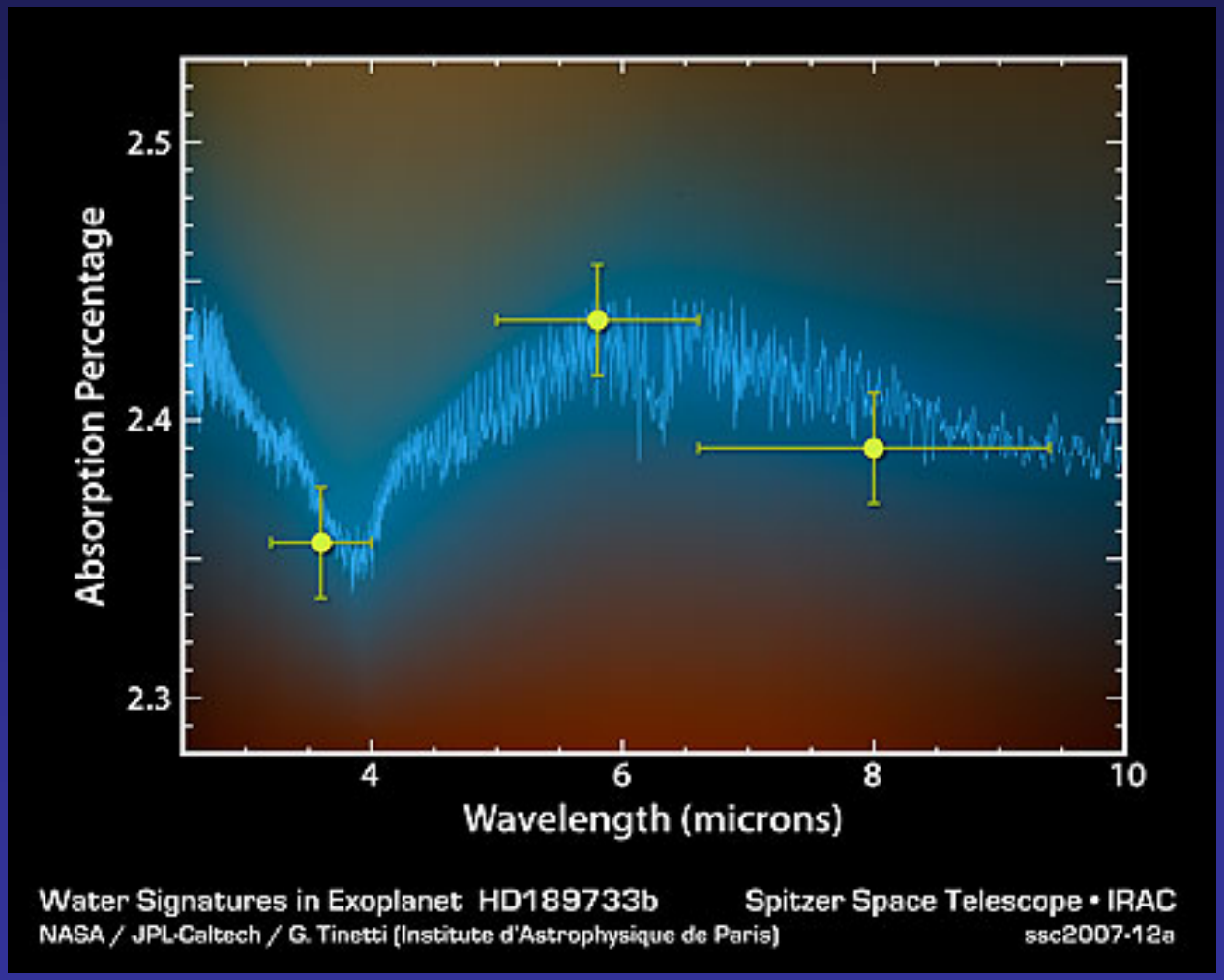
Knutson et al.

Temperature inversion on 209



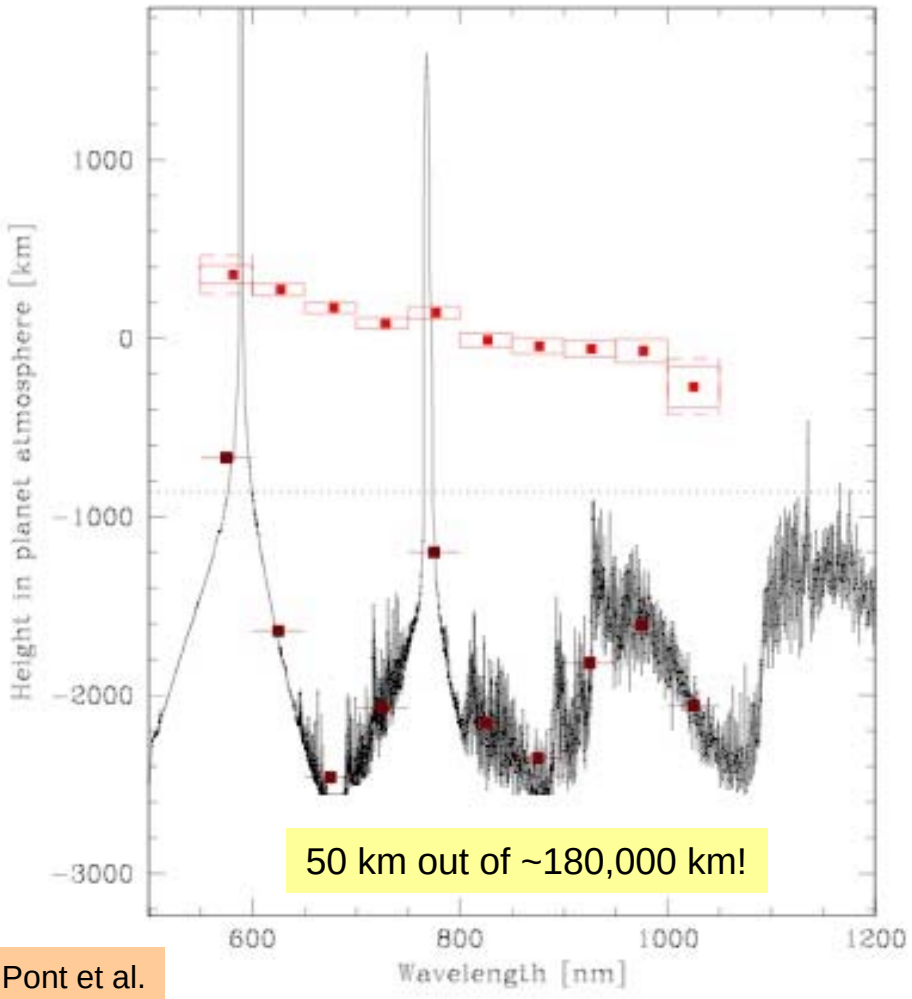
Water detected on 189733b

2007



Haze on 189
2007

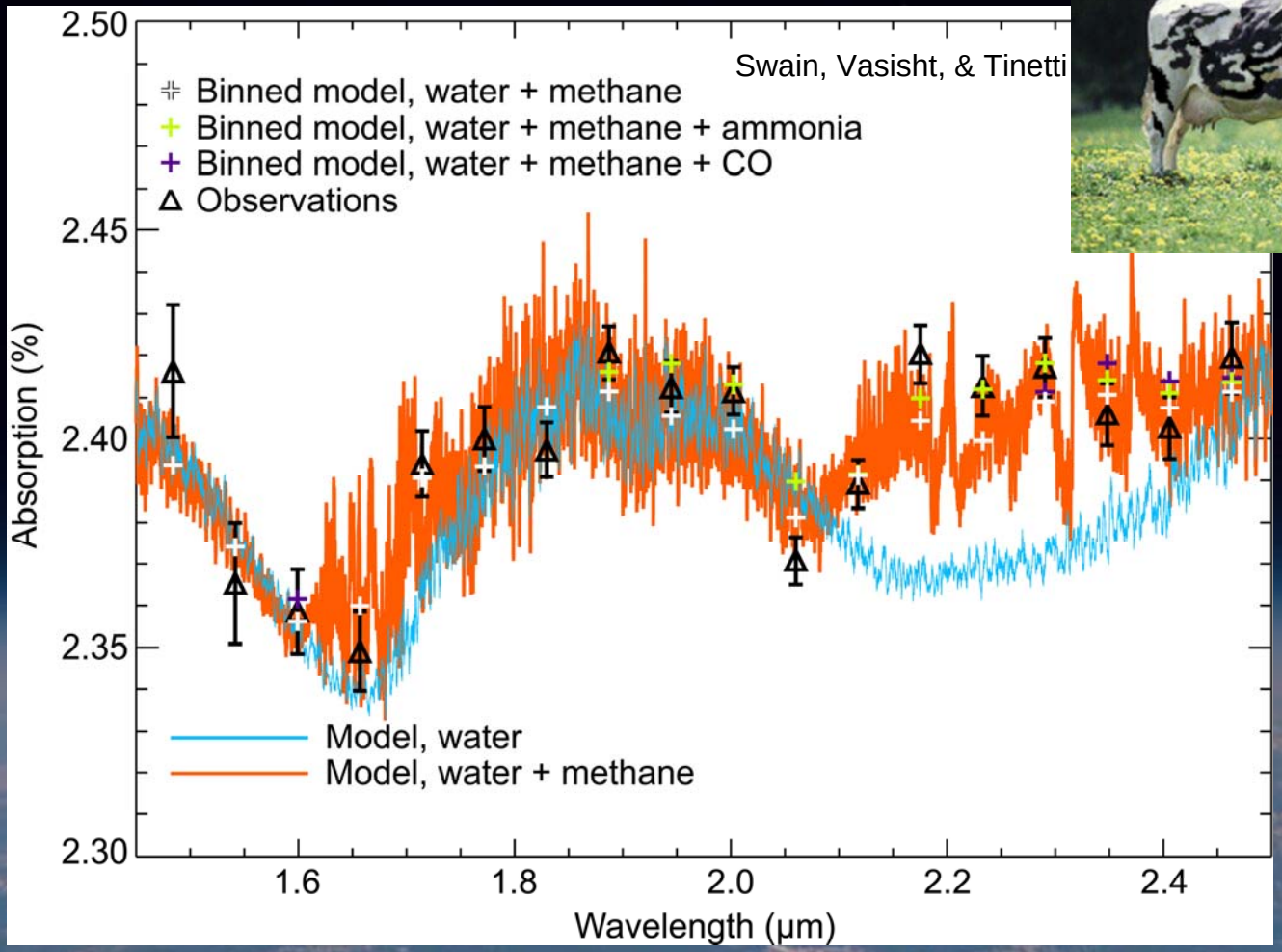
- Visible transmission spectrum
- Small particles at high altitude
- Would Al Gore care?



Pont et al.

Methane detected in an exoplanet atmosphere

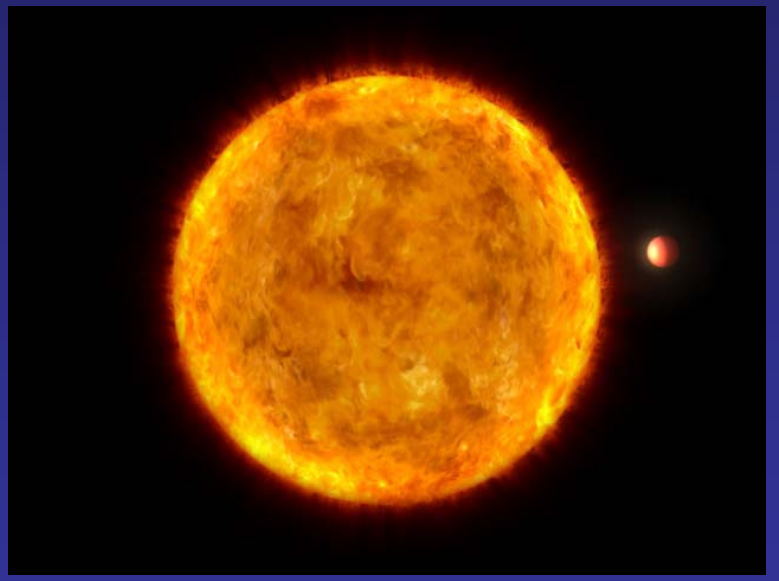
?



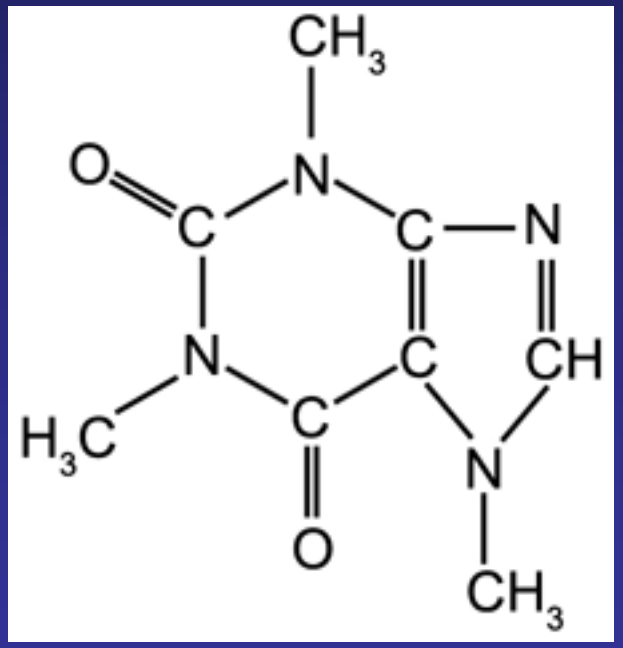
The future

Emerging Themes:

- Molecules
  - Probe conditions, composition, and chemistry
  - Require spectroscopy
- Localization
  - Spatially resolved abundances
  - Dayside vs nightside chemistry
  - Diagnostic of photochemistry & dynamics
- Variability
  - Weather
  - Non-transiting planets



I’ll still be looking for ….



caffeine

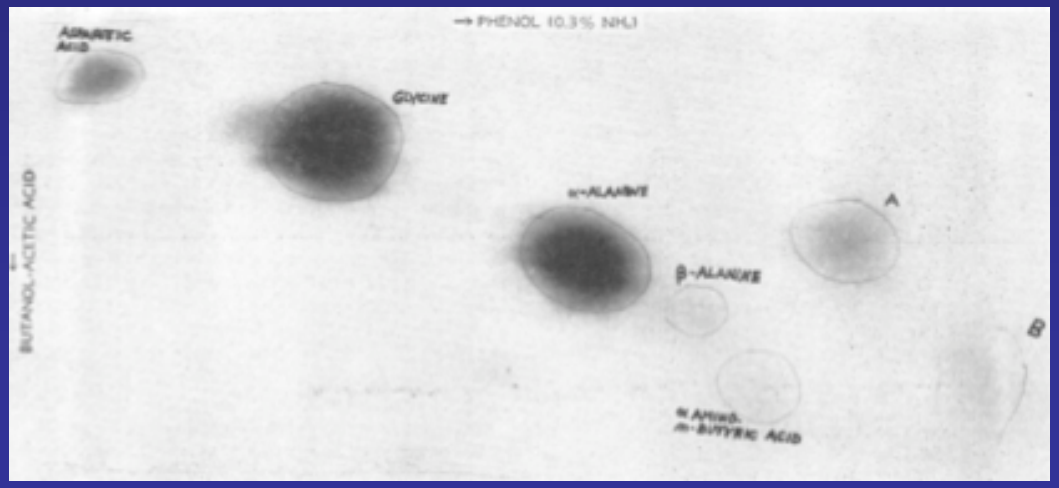
To answer the question: "Are we alone?"

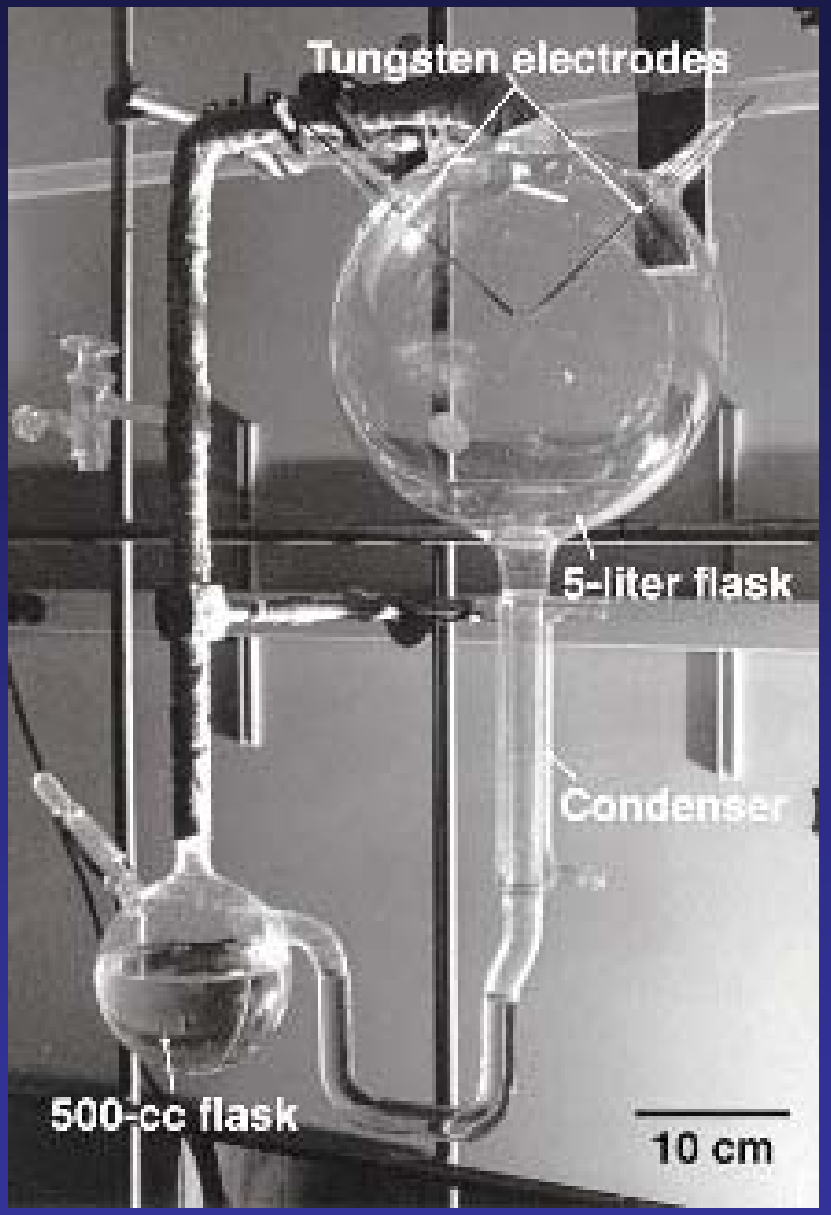
- ✓ Are there planets around other stars? (exoplanets)
- ✓ Could they support life?
- ✓ What kind of atmosphere?
- ✓ Are organic molecules present?
- ? Are there "biomarkers"?

Prebiotic molecules:

the building blocks of DNA

- Synthesis of amino acids (Miller 1953, Science)
- $CH_4 + NH_3 + H_2O + H_2$ + electric discharge → glycine, α-alanine, β-alanine

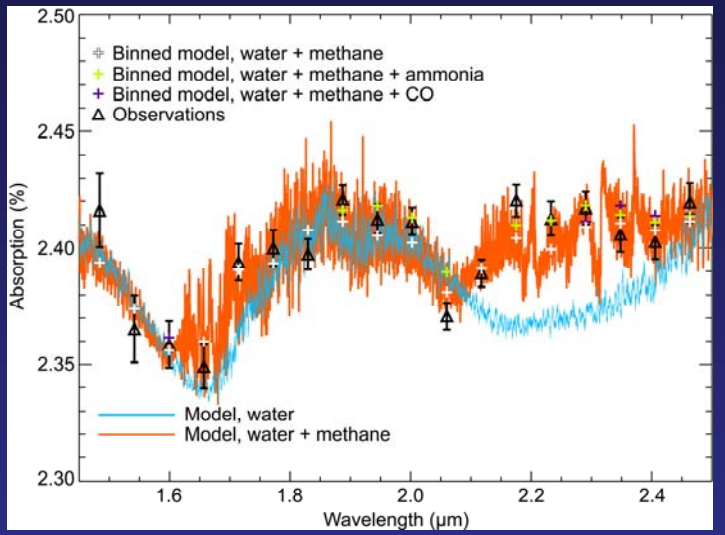




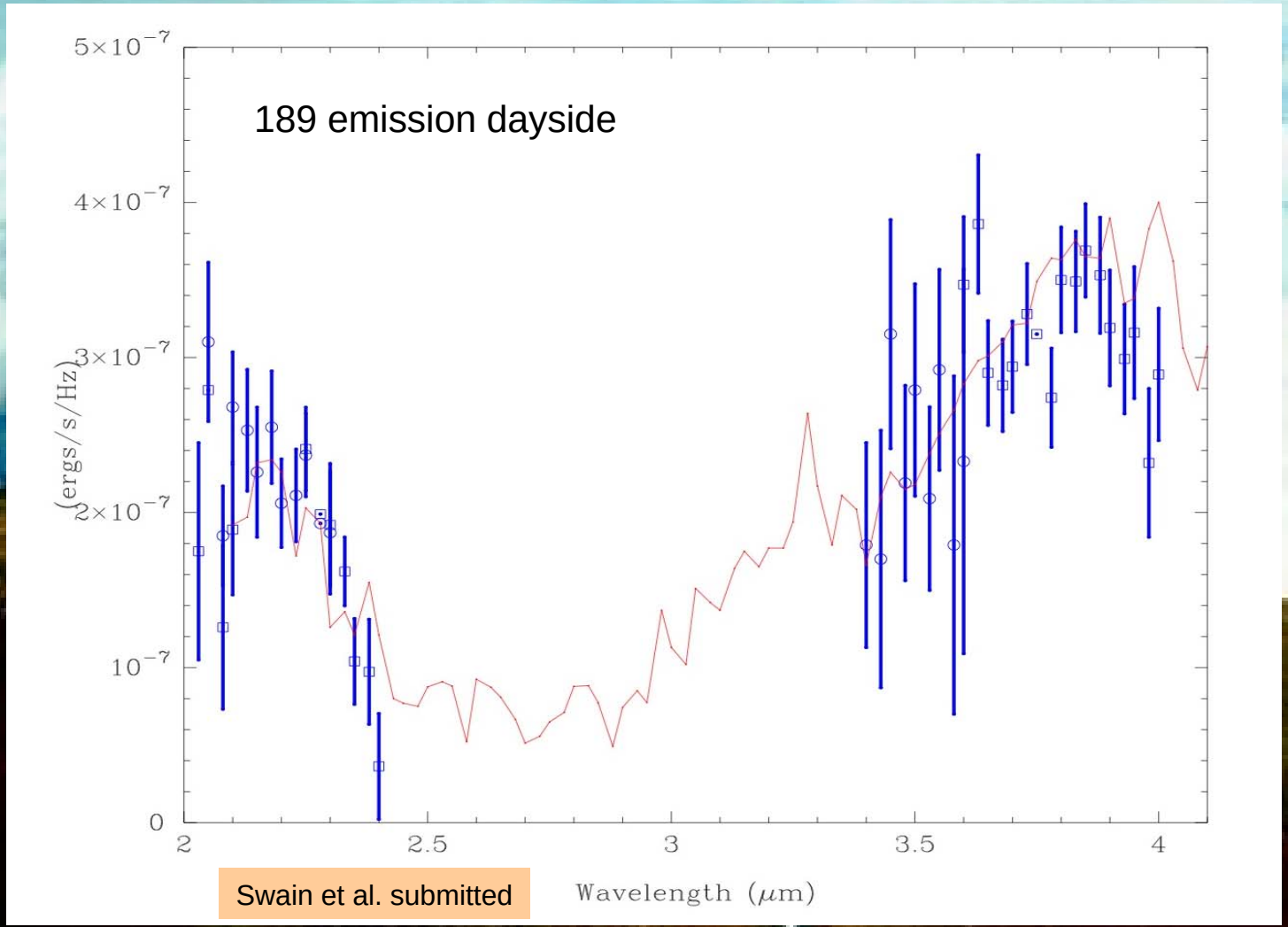
Hubble measurement implications:

enter the molecules

- Hubble can characterize numerous exoplanets.
- Water, methane, carbon monoxide, carbon dioxide, and ammonia can be measured.
- Small telescopes useful; SNR ~ D.
- Given the appropriate target, we could measure organic molecules on a habitable-zone exoplanet today.
- GJ 436b is “almost there” (Neptune mass, 700 K, hydrogen rich)



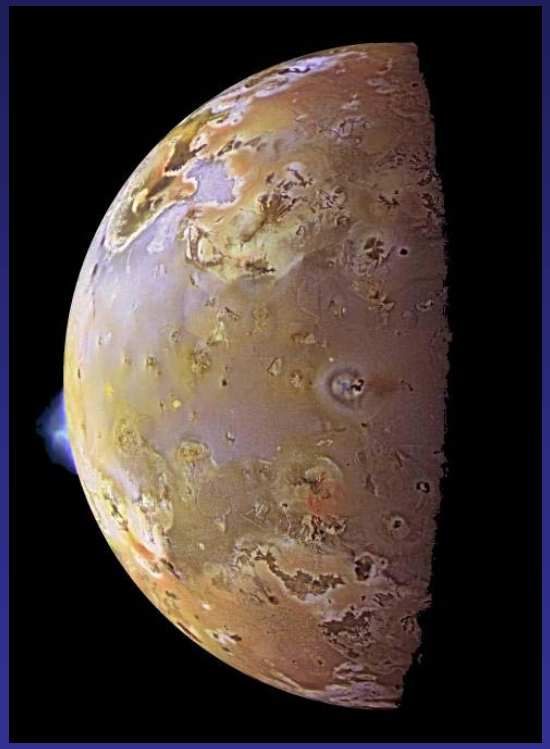
The ground joins the show

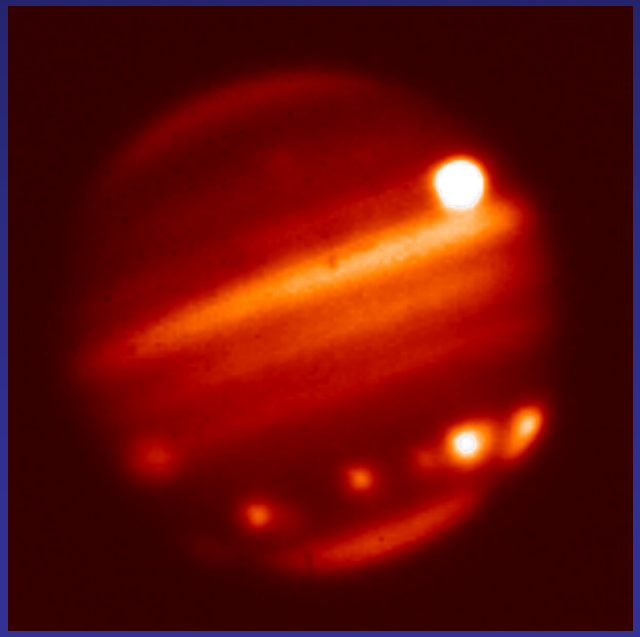


Swain et al. submitted

Variability

Spitzer implications



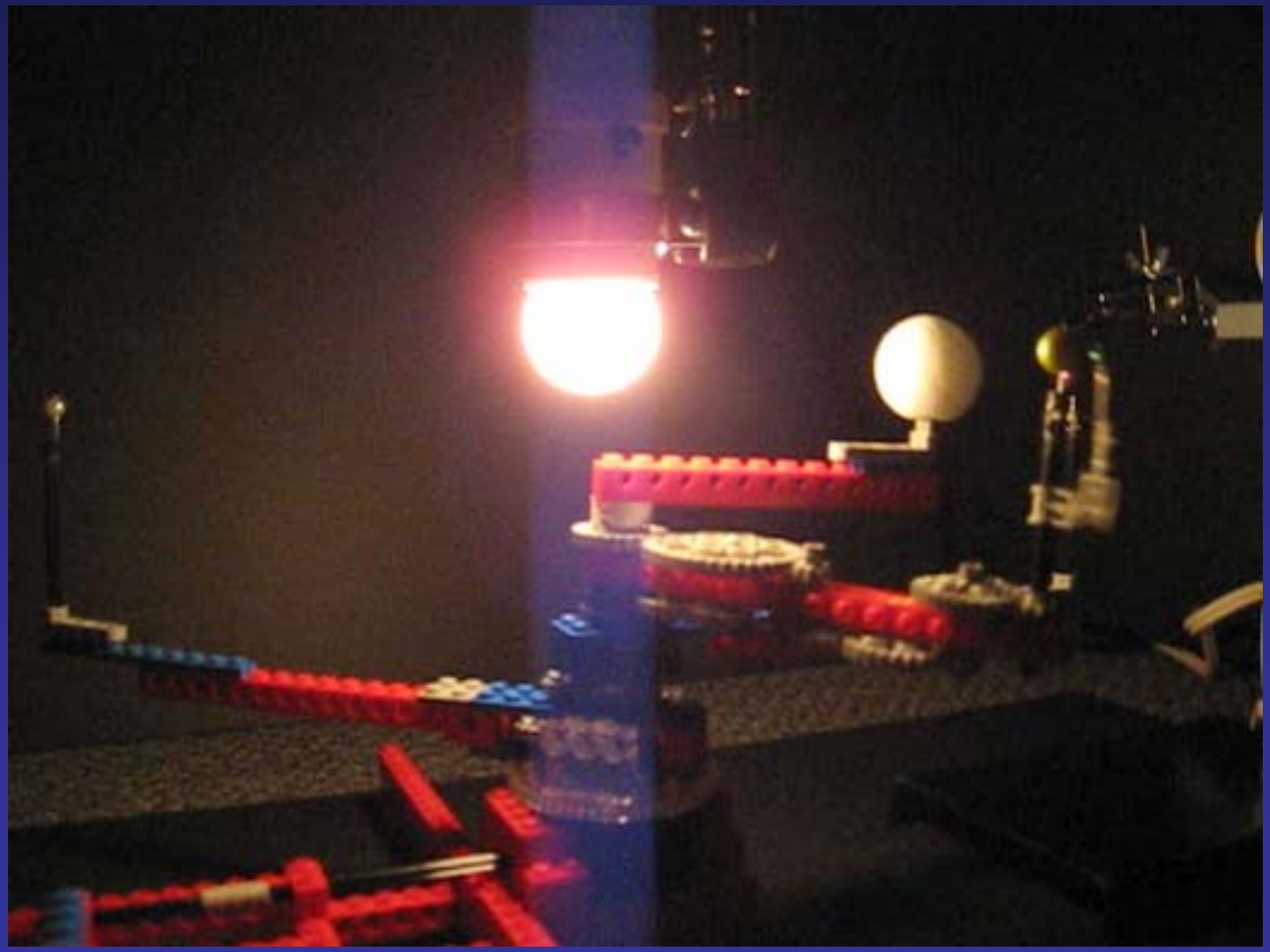


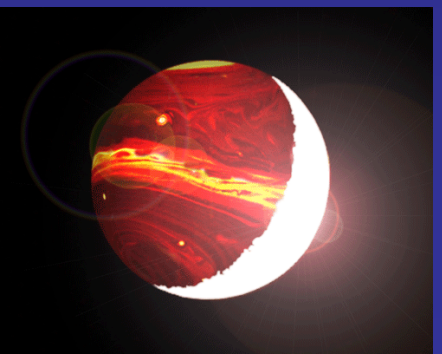
QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Swain & Bouwman

Non-transiting planets

a dramatic increase in possible targets





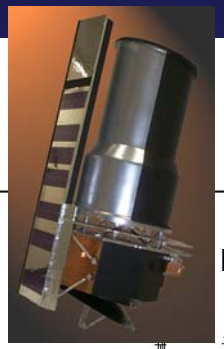
Five Myths:

exoplanet spectroscopic characterization requirements

- Transits
- Bright targets
- Large telescope
- New instrument technology
- Exceedingly difficult

The Balloon-borne Exoplanet Spectroscopy Telescope (BEST)

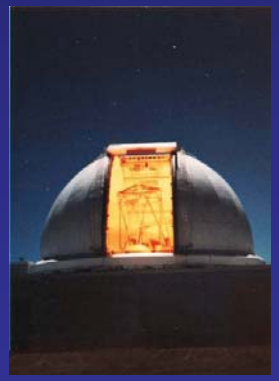
completing the picture



Characterizing exoplanet atmospheres

the near future & further future

- nightside spectra
- non-transiting planet's spectra
- numerous molecules detected
- atmospheric chemistry
- characterization of HZ planet



- atmospheric changes
- surface characterization
- chemistry of organic molecules

A grand adventure!